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GAS SAMPLING AT THE POINT TUPPER AFBC FACILITY

a report prepared by

Michel F. Couturier
Assistant Professor
Chemical Engineering Department
University of New Brunswick
Fredericton, New Brunswick
Canada E3B 5A3

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Energy, Mines and Resources Canada
Energy Research Laboratories, CANMET
Ottawa, Canada

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ABSTRACT

The O_2, CO_2, CO, NO_X and SO_2 concentration profiles within the fluidized bed coal combustor in Point Tupper, Nova Scotia were determined by extractive gas sampling between July 23 and 27, 1985. Highly reducing zones were found near the coal feed nozzle and it appears that some combustion air was bypassing the fluidized bed. It is concluded that the plume model of Park, Levenspiel and Fitzgerald is a realistic representation of the gas flow patterns in fluidized bed combustors.

Sommaire

Les profils de concentration des gaz suivants: O_2, CO_2, CO, NO_X et SO_2, ont été déterminé à l'intérieur de la fournaise à charbon avec lit fluidisé à Point Tupper, Nouvelle-Ecosse entre le 23 et 27 juillet, 1985. Des zones de réduction furent trouvées près du point d'entrée du charbon et il semble qu'une partie de l'air pour la combustion contournait le lit fluidisé. Il est conclu que le modèle mathématique de Park, Levenspiel et Fitzgerald est une représentation réaliste de la circulation des gaz dans une fournaise à charbon avec lit fluidisé.

PREFACE

This is the final report on work performed under a contract with Supply and Services Canada:

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Principal investigator: Michel Couturier, Assistant Professor, Chemical Engineering Department, University of New Brunswick, Fredericton, New Brunswick E3B 5A3. Telephone: (506) 453-4519.

Scientific authority: Dr. E.J. Anthony, Energy Research Laboratories, CANMET, 555 Booth Street, Ottawa, Ontario K1A 0G1. Telephone: (613) 996-4570, ext. 185.

Science contracting officer: Mrs. J.P.S. Sztramko, Science and Professional Services Directorate, Supply and Services Canada, 11C1 Place du Portage, Phase III, 11 Laurier Street, Hull, Quebec K1A 0S5. Telephone: (819) 997-7398.

Commencement date: April 15, 1985.

Delivery date: September 5, 1985

The overall management of the gas sampling program was undertaken by Michel Couturier, Assistant Professor, Department of Chemical Engineering, University of New Brunswick. UNB's responsibilities included design of the gas sampling probe, technical direction, supervision and preparation of the final report. The construction of the probe and on-site data collection was subcontracted to the Research and Productivity Council. Dr. Philip Salib and Mr. Ross Robson from RPC were responsible for the execution of the subcontract.

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This project would not have been possible without the full cooperation received from the Nova Scotia Power Corporation. Special thanks must be given to Messrs. David Briggs and Bill Richards from NSPC for their constant help during the project.

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1. INTRODUCTION

The Nova Scotia Power Corporation with the support of the Governments of Nova Scotia and Canada has recently completed a 10,000-hour corrosion experiment using a 1 m^2 pilot-scale fluidized-bed combustor built on the site of the Point Tupper Generating Station near Port Hawkesbury, N.S. The corrosion program consisted of exposing a number of specimen probes to the environment within the atmospheric fluidized bed combustor (AFBC) for a series of ten 1,000-hour test runs.

During the first seven 1000-hour corrosion trials, the corrosive nature of the environment surrounding the corrosion specimens was determined only by measuring the O_2 concentration at several locations within the bed using a platinum-zirconia type oxygen sensor. It was then decided that measurements of gas concentrations by extractive gas sampling might also be very useful in analyzing the corrosion results and assist in future developments of the AFBC technology. Hence, on January 23, 1985, the University of New Brunswick submitted an unsolicited proposal to the Federal Government for a program to measure the O_2, CO_2, CO, NO_x and SO_2 concentrations along the freeboard and in the bed of the Point Tupper fluidized-bed combustor. The program was approved and began on April 15, 1985. The principal findings of the program are described in this report.

2. EXPERIMENTAL MEASUREMENTS

2.1 Gas sampling system

The fundamental problem in sampling from any system is to ensure that a representative sample is obtained. Indeed, sampling difficulties are very often the actual causes of analytical anomalies, and advantages presumably gained by using advanced analytical instruments can be negated by sampling flaws. There are four major areas of concern related to continuous gas sampling:

1) Obtaining a truly representative sample of the flowing gas stream. The sample must be taken with minimal thermal, chemical or fluid-mechanic disturbances to the system, otherwise the measurements will be made on a combustion system different from the one intended to be investigated. Also, the gaseous reactions must be quenched rapidly at the probe entrance in order to conserve the original concentration of the constituents. Furthermore, gas sampling at any localities within the combustor must be done continuously for at least three minutes in order to get a reproducible mean concentration of the gaseous species. The concentration of the gases fluctuates with time and a much shorter sampling duration is not suitable if a representative mean concentration is required.

2) Conditioning the sample and transporting it to the analyzers without altering the concentration ratio of the components to be monitored. The sample must be conditioned before being analyzed because the analyzers are designed to operate within a small temperature and pressure range with dry, particulate-free, non-corrosive, non-interfering samples. The gaseous species may be partly lost along the transport line because of homogeneous reactions, catalytic reactions or adsorption on the walls of the transfer system, and condensation or dissolution in condensates formed along the sampling line. Furthermore, if extensive adsorption of some species has occurred on the walls of the transfer system, desorption of these species when sampling lower concentrations can lead to erroneously high concentration values.

3) Accurately measuring the species of interest. The analyzers must be properly calibrated and maintained in good working order so that the concentration of the gaseous components may be monitored continuously and accurately.

4) Sampling system durability. The probe must be able to withstand the high-temperature, corrosive atmospheres present in the combustor whereas the pump and analyzers must be able to operate for long periods without requiring major repairs.

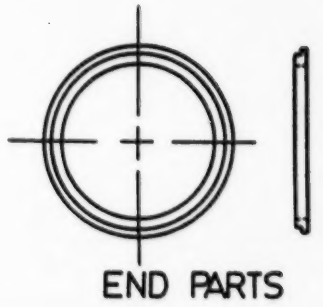
The assembly details of the probe used during the gas sampling program are shown in Figure 2.1.1. An alundum thimble (44.5 mm O.D. x 127 mm long x 1.5 mm wall thickness) supplied by Norton Canada Inc., Hamilton, Ontario, was located at the tip of the probe for in-situ filtering of the solid particles. The alundum filter was held in place by a semi-opened, stainless-steel, threaded holder (Part 1 in Figure 2.1.1). A high-temperature thread lubricant was used to prevent seizing of the threaded parts.

The probe was water-cooled to maintain structural strength at the high temperatures encountered in the AFBC. However, the inner 1/4 inch gas sampling tube was maintained at 150°C by an electrical heating tape (not shown in Figure 2.1.1). The electrical heating tape was wrapped around the gas sampling tube and the annulus between the 1/4 inch and 1 1/2 inch tubings was filled with insulation. The temperature of the gas sampling tube was measured using two thermocouples located on the outside of the 1/4 inch gas sampling tube.

Any solid particles that passed the alundum filter were prevented from entering the gas sampling line and analytical system by a small stainless-steel filter located at the rear of the probe. There was also provision for an air purge line at the rear of the probe to back flush the alundum filter in case of plugging.

The volumes of the probe and of the gas sample (~2 ℓ/min at STP) were small enough as to cause minimal interference to the combustion system. Furthermore, sample alteration due to relaxation of radical species within the probe was of no concern because free radicals are in very low concentrations at the relatively low operating temperatures of fluidized-bed combustors (800°C-1000°C). Also, the

Item	Description
1	Alundum filter $1\frac{3}{4}$" O.D. x 5"L.
2	Gasket $2\frac{1}{16}$" O.D. x $\frac{7}{8}$" I.D. x $\frac{1}{8}$" thick
3	2" S.S. tubing, 0.065" W.T., 8' L.
4	$1\frac{3}{4}$" S.S. tubing, 0.065" W.T., 8' - 1" L.
5	$1\frac{1}{2}$" S.S. tubing, 0.065" W.T., 8' - 8" L.
6	$\frac{1}{4}$" S.S. tubing, 0.035" W.T., 9' L.
7	$\frac{3}{4}$" S.S. tubing, 0.065" W.T., 1'L.
8	$\frac{1}{4}$" S.S. Swagelok reducer



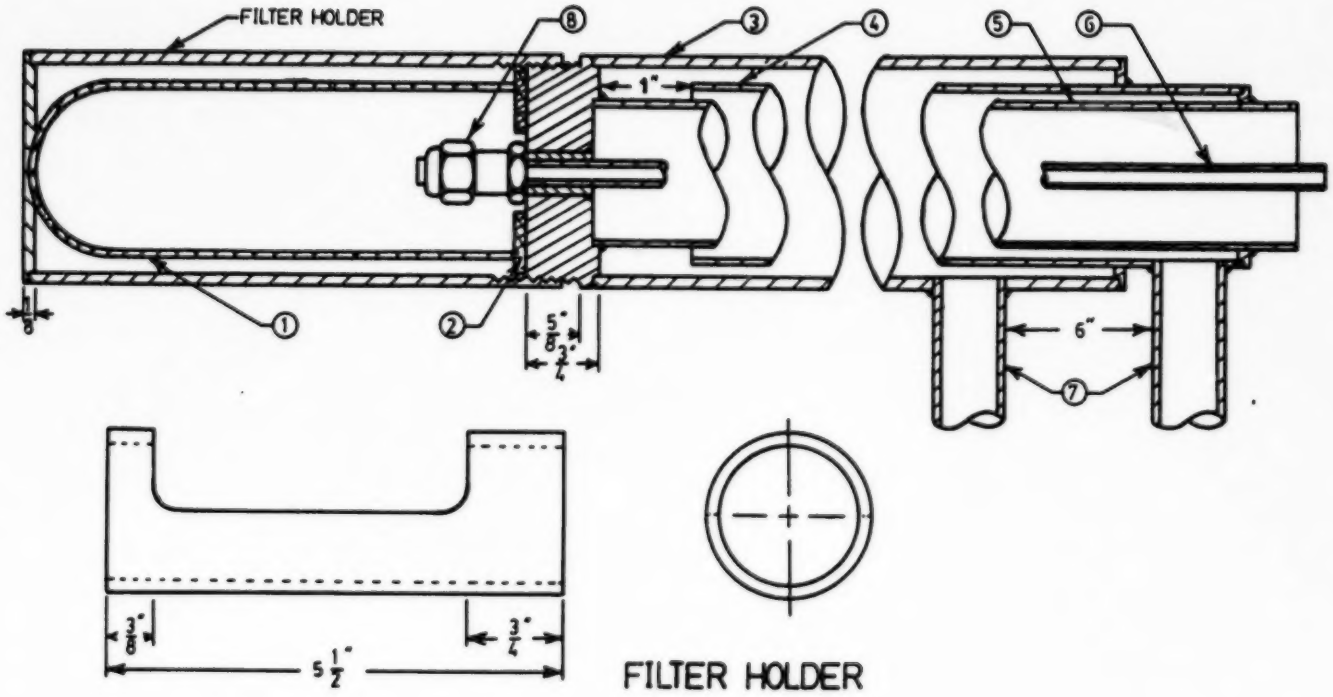


Fig. 2.1.1. Gas sampling probe

quenching by convection within the probe was undoubtedly fast enough so that very little CO was converted to CO_2 within the sampling probe. However, the catalytic effect of the alundum filter on the sample composition is not known but is believed to have been negligible.

The probe was linked by a 24.4 m long electrically heated teflon line to the existing analytical system of the pilot-plant. The teflon sampling line was supplied by Technical Heaters Inc., San Fernando, California. The entire gas-sampling transportation line was maintained at 150°C so that no water, sulphuric acid or hydrocarbons would condense along the sampling interface. Also, all lines and fittings in contact with the gas sample were made of teflon or stainless-steel to prevent interferences due to gas adsorption or heterogeneous reactions.

The analytical system provided continuous determination of the concentration of the following gas sample constituents: O_2, CO_2, CO, SO_2 and NO_x. In some cases, the CO content of the gas sample exceeded the upper range (4000 ppm) of the CO analyzer in the analtyical system, and a second infrared CO analyzer on loan from CANMET and having an upper scale of 5% CO was then used. The analytical system had a cold trap located just before the gas analyzers and all hydrocarbons, water and acids contained in the gas sample were removed at that point. Hence, all the measured gas concentrations were on a moisture-free basis. The accuracy of the pilot-plant's analytical system had been verified on a routine basis by NSPC personnel prior to the gas sampling program.

2.2 Procedure

The gas sampling program took place during the period from July 23 to July 27, 1985. Gas samples were taken from ten sampling ports located along the length of the combustor: five ports were located in the fluidized-bed, two were in the splash zone and three were in the freeboard.

The labelling and location of the sampling ports is indicated in Figure 2.2.1. All sampling ports except ports W19 and N21 were located on the south side of the combustor. Port W19 was located on the west side whereas port N21 was located on the north side.

In each of the sampling ports, the average CO_2, CO, SO_2, O_2 and NO_x concentrations have been determined twice at three equally spaced locations. The average concentration of a gas species at a given sampling location was obtained by recording its instantaneous concentration every minute for a period of ten minutes and then averaging the ten readings. The standard deviation of the ten readings was also calculated to provide an indication of the magnitude of the fluctuations in composition during the ten minute sampling period.

2.3 Experience gained

The design of the original sampling probe was identical to that shown in Figure 2.1.1 except that the outside diameter of the probe was 60.3 mm. Upon arrival on site, it was discovered that although all ports had an inside diameter of 63.5 mm, some of them were mounted with a ball valve (used to seal the port when unused) whose opening was slightly smaller than the outside diameter of the probe. Furthermore, it was very difficult to insert the probe in the remaining usable ports because solid particles would unavoidably get jammed in the small annulus between the probe and the inside wall of the ports. Hence, it was decided to build the 50.8 mm O.D. probe shown in Figure 2.1.1. This latter probe could fit easily in the freeboard sampling ports if they were cleared by a blast of air before probe insertion. The probe could also be easily introduced in the in-bed sampling ports as long as the ports were continuously purged with air while the probe was being inserted or withdrawn.

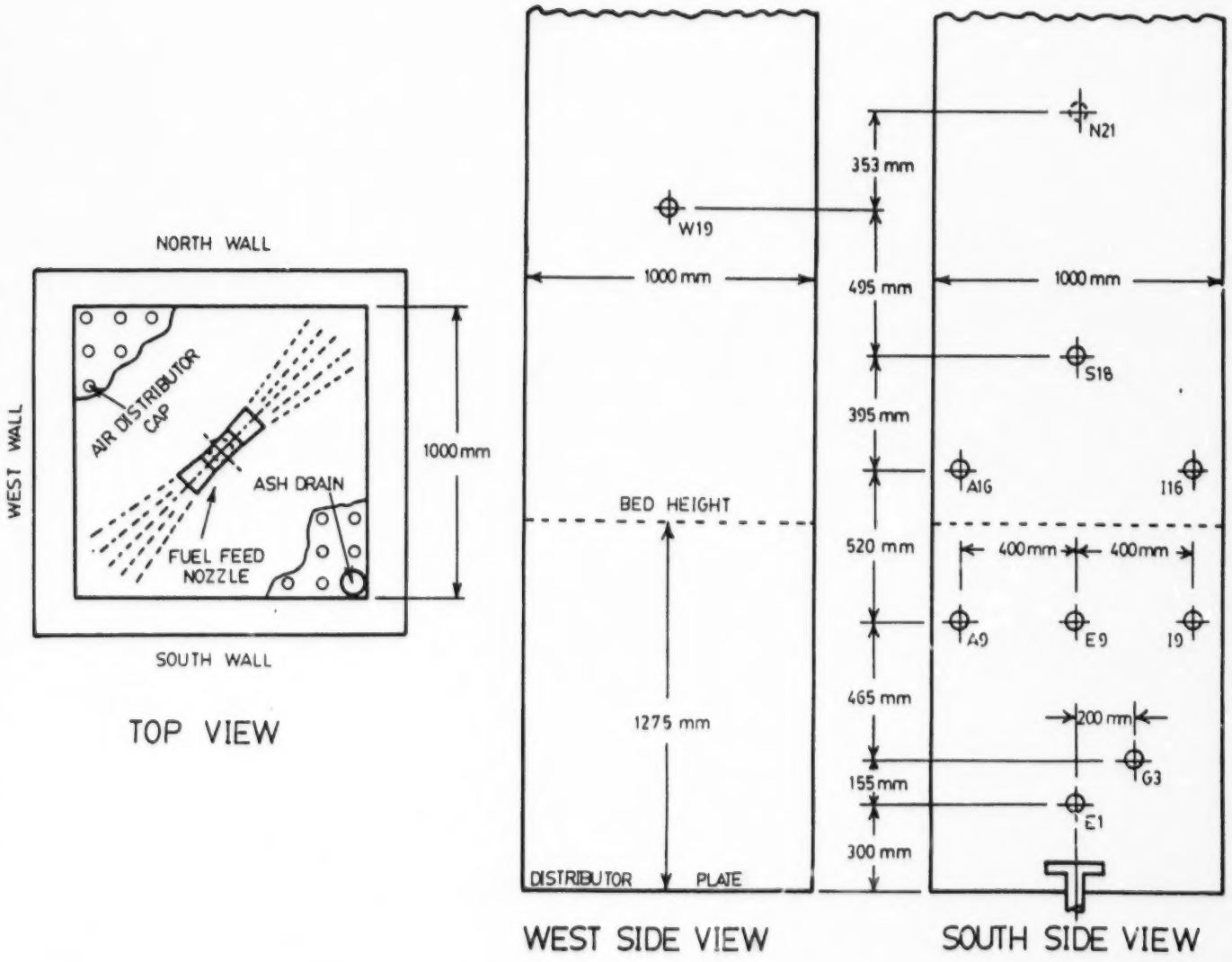


Fig. 2.2.1. Position and labelling of the sampling ports

The initial alundum-filter holder had opened top and bottom halves but was soon found unsatisfactory because the violent periodic upward movements of the solids in the fluidized-bed were breaking the alundum filter. That problem was solved by shielding the bottom half of the filter using the semi-opened filter holder shown in Figure 2.1.1.

The alundum filters were very effective in separating the gases from the solids in situ. Their large surface area made it possible to use large sample gas flowrates and plugging problems were rarely encountered. In fact the filters usually cracked before they would plug. The thermal shock encountered by the filters upon their entry or exit from the combustor appeared to have been the cause for the cracking of the filters. Hence, in most cases the two sets of readings made at a given port were obtained consecutively in order to maximize the life of the filters. The first set of readings was obtained by initially positioning the probe at 750 mm from the inside of the wall on which the port was located, then at 500 mm and finally at 250 mm. The second set of readings was then obtained by immediately repeating the same procedure before withdrawing the probe from the combustor.

3. RESULTS

A summary of the results obtained is shown in Appendix A. For each port, the O_2, CO_2, CO, NO_x and SO_2 concentrations were determined at three equally spaced locations across the combustor: 750 mm, 500 mm and 250 mm (all distances were measured from the inside of the wall on which the sampling port was located). Two sets of measurements were made at each port and are denoted in Tables A.1 to A.10 by measurement series A and B.

The operating conditions of the combustor were recorded at every sampling location and the overall average operating conditions from July 23 to July 27, 1985 are shown in

Table 3.1. The bed temperature, bed height, air flow and recycle rate were very constant during the sampling program as indicated by their small standard deviation presented in Table 3.1. However, the coal and limestone flowrates varied by as much as ±20% of their calculated mean during the four day sampling period.

The concentration of the gas species stayed relatively constant during the ten minute sampling period in all sampling ports except in ports E1 and G3. The concentration of the gas species, especially CO, fluctuated over a large range of values in ports E1 and G3, as indicated by their large standard deviations shown in Tables A.1 and A.2. However, the large fluctuations in concentration and large CO readings observed in ports E1 and G3 were not surprising because these ports were next to the fuel feed nozzle, as shown in Figure 2.2.1.

The average O_2 concentrations presented in Appendix A are plotted for each port as a function of position in Figure 3.1. The plots in Figure 3.1 are positioned with respect to each other in the same general way as the ports are laid out in Figure 2.2.1. In all the plots of Figure 3.1 except the plot for port W19, the 0 mm position is at the inside surface of the south wall and the 100 mm position is at the inside surface of the north wall (see Figure 2.2.1 for the labelling of the combustor walls). The 0 mm position for port W19 is at the inside surface of the west wall whereas the 1000 mm position is at the inside surface of the east wall. Similar plots have been prepared for the CO_2, CO, NO_x and SO_2 concentrations in Figures 3.2, 3.3, 3.4 and 3.5, respectively.

The O_2, CO_2 and CO concentrations in the middle ports (i.e., ports E1, E9, S18, W19 and W21) have also been plotted as a function of height above the distributor plate in Figure 3.6. Similar plots for SO_2 and NO_x are presented in Figure 3.7.

Table 3.1 Average operating conditions during the sampling program

	mean	standard deviation
Coal flow (kg/hr)	360	36
Limestone flow (kg/hr)	60.0	6.0
Air flow (kg/hr)	2825	56
Flue gas O_2 (%)	3.03	0.14
Bed temperature (^{o}C)	851	3.9
Bed height (mm)	1275	14
Recycle rate (kg/hr)	513	15

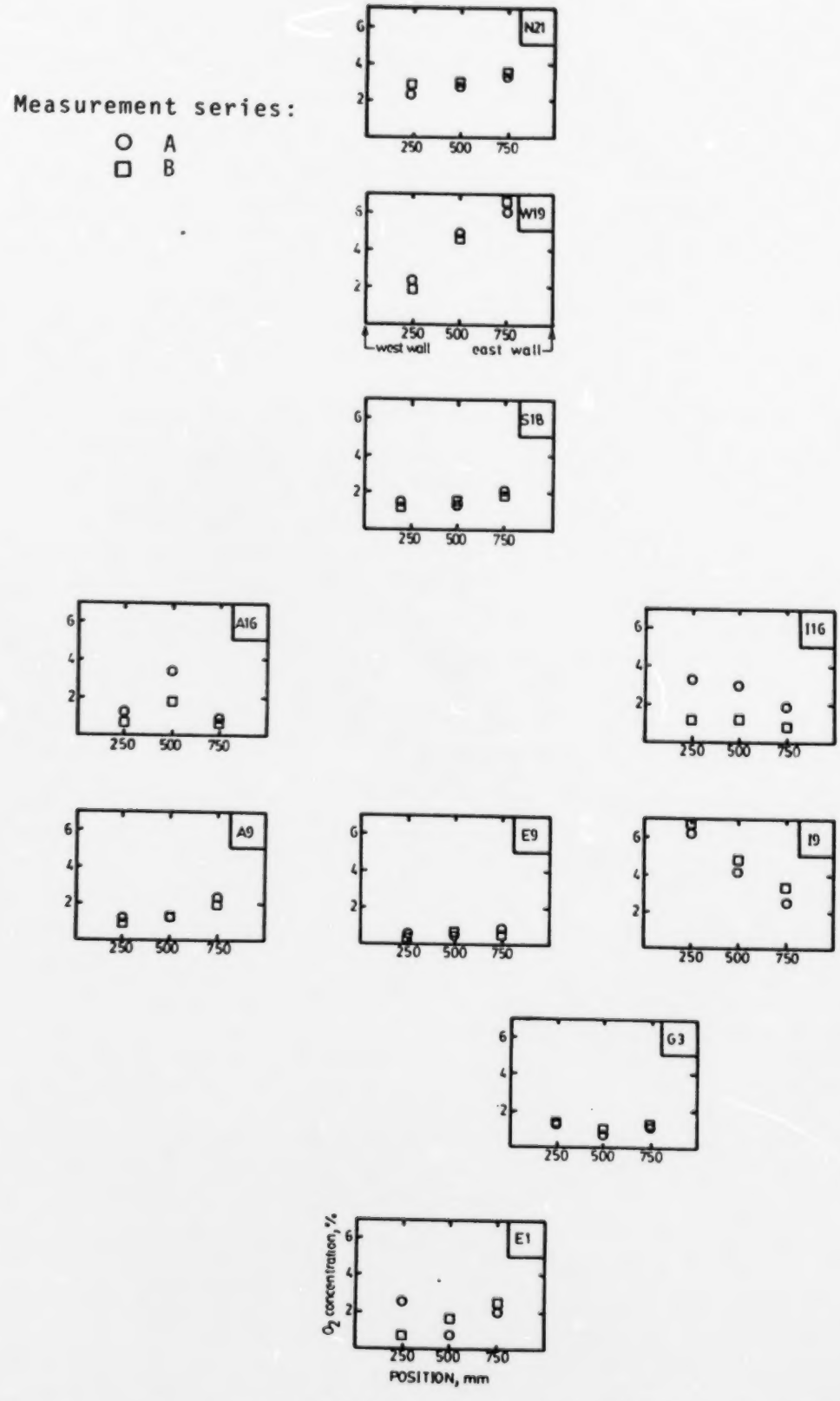


Fig. 3.1. O_2 concentration (%) versus sampling position (mm) in each port. Zero and 1000 mm positions correspond respectively to inside of south and north walls unless otherwise indicated.

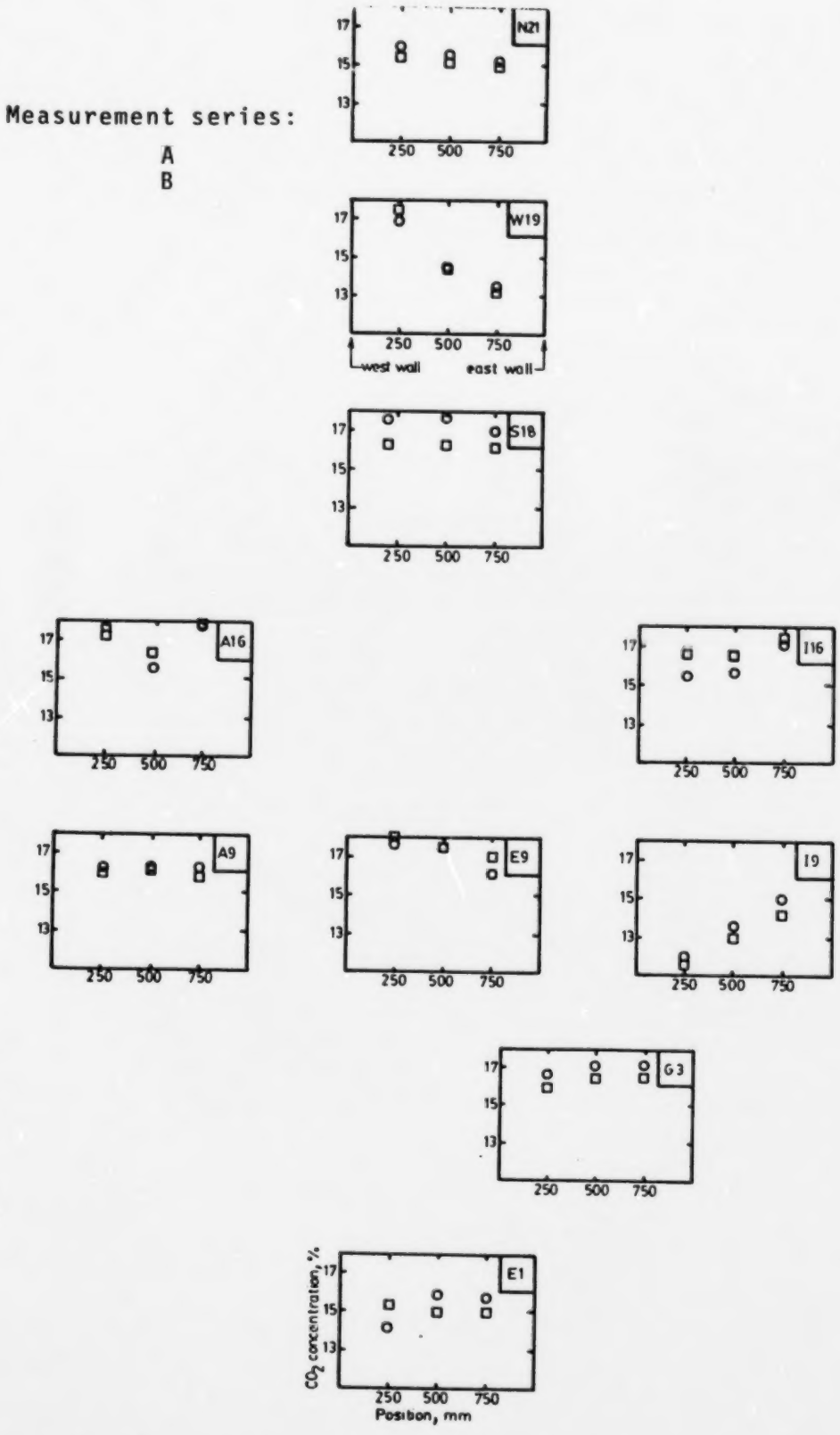


Fig. 3.2. CO_2 concentration (%) versus sampling position (mm) in each port. Zero and 1000 mm positions correspond respectively to inside of south and north walls unless otherwise indicated.

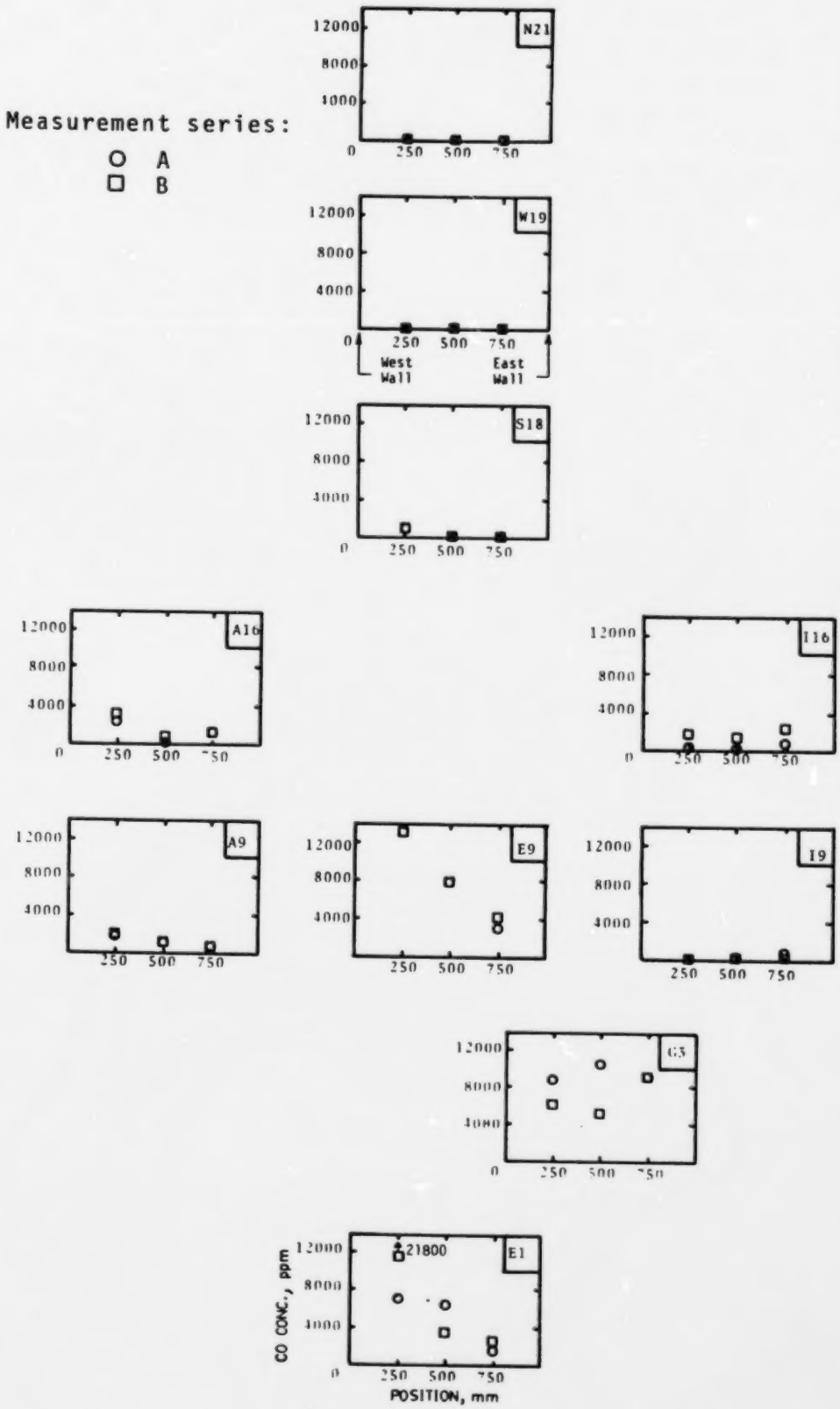


Fig. 3.3. CO concentration (ppm) versus sampling position (mm) in each port. Zero and 1000 mm positions correspond respectively to inside of south and north walls unless otherwise indicated.

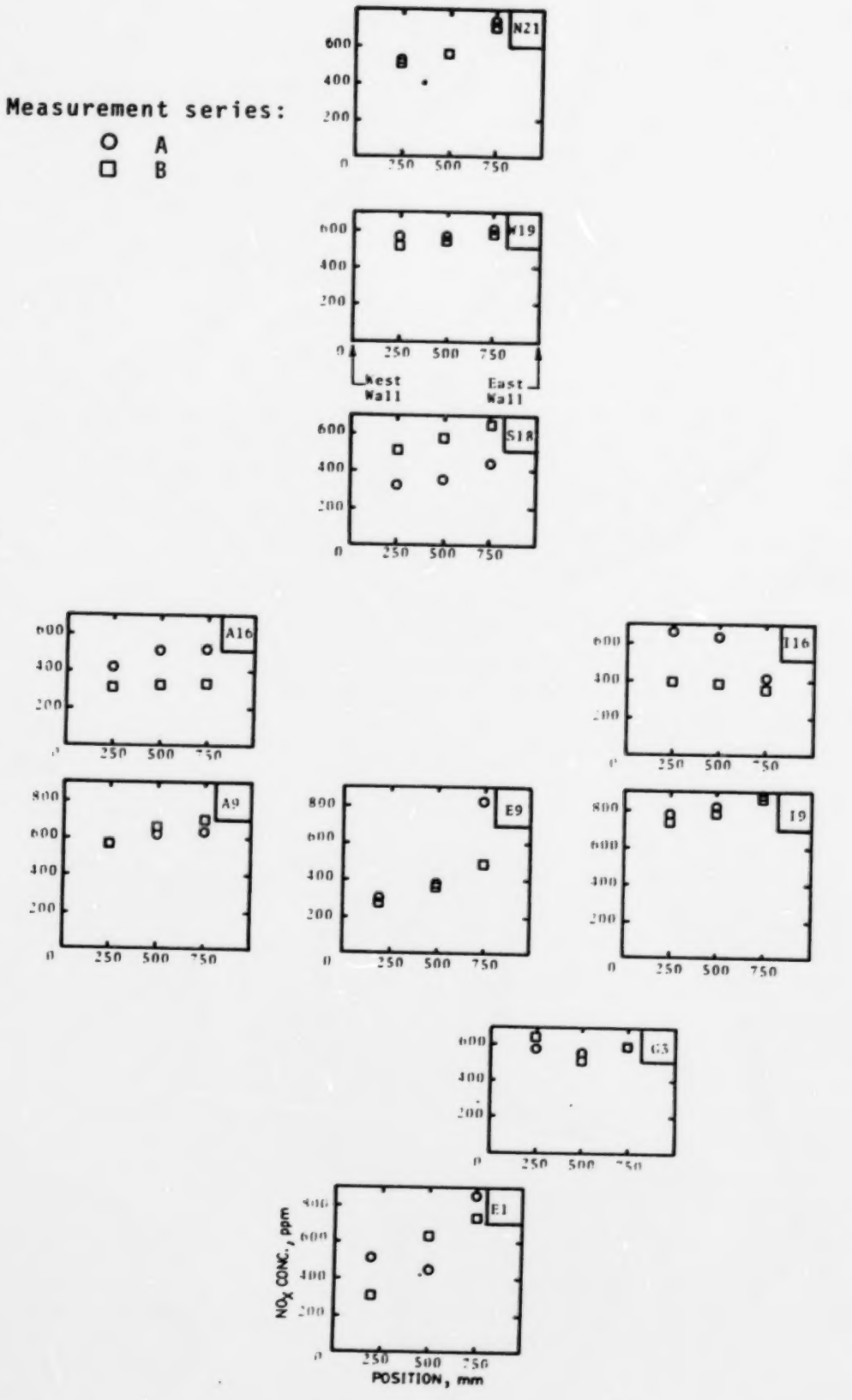


Fig. 3.4. NO_X concentration (ppm) versus sampling position (mm) in each port. Zero and 1000 mm positions correspond respectively to inside of south and north walls unless otherwise indicated.

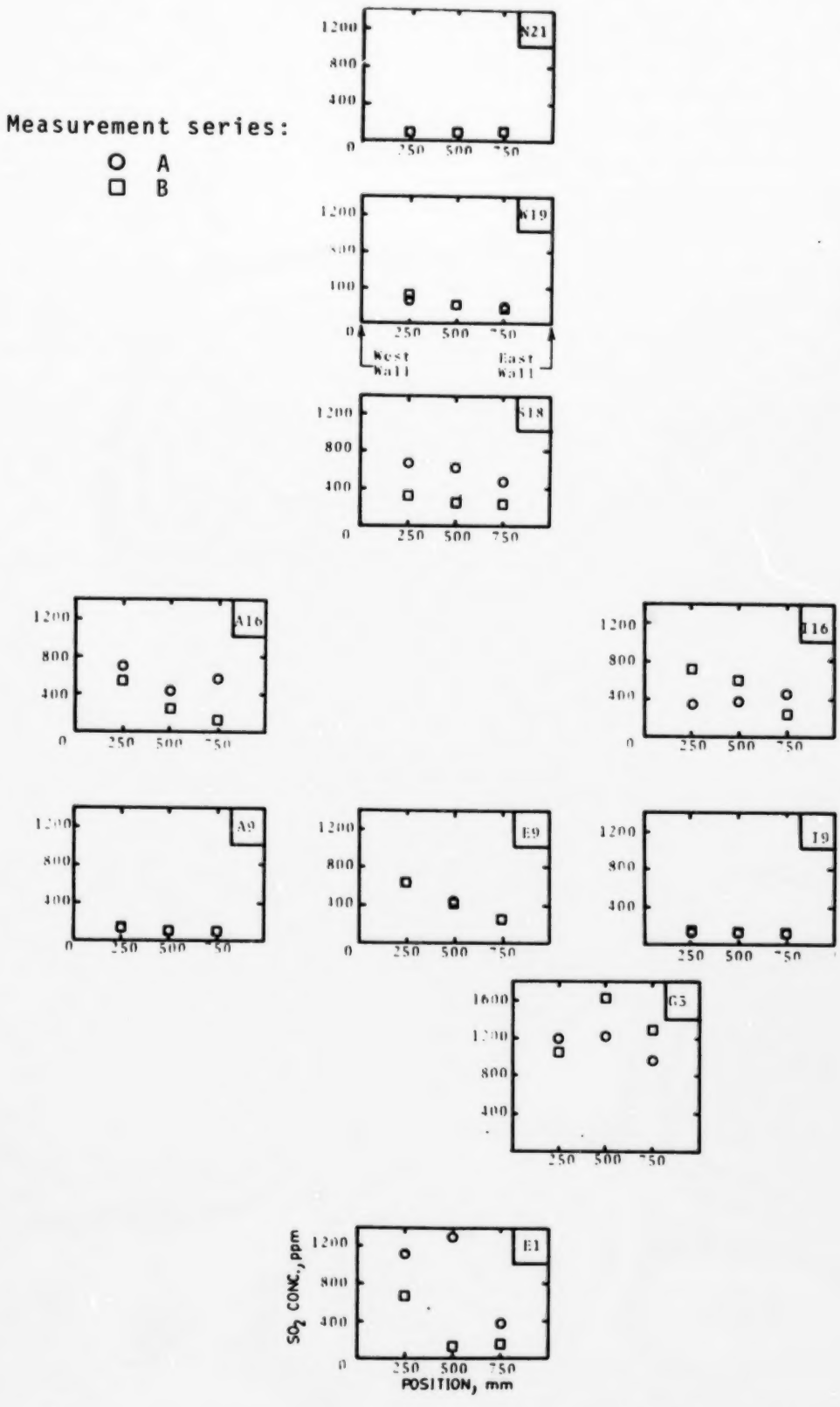


Fig. 3.5. SO_2 concentration (ppm) versus sampling position (mm) in each port. Zero and 1000 mm positions correspond respectively to inside of south and north walls unless otherwise indicated.

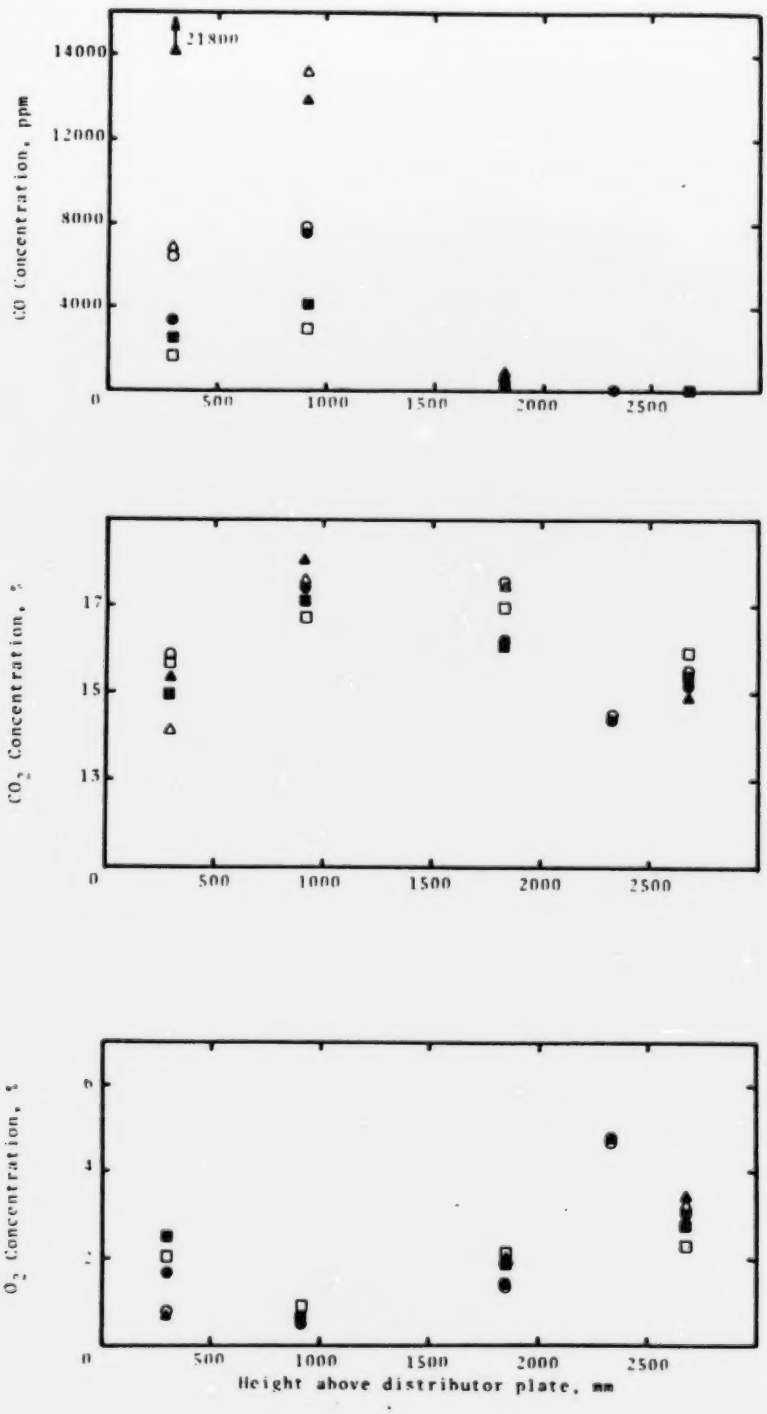


Fig. 3.6. O_2, CO_2 and CO concentrations in middle ports versus height above the distributor plate. Sampling location as measured from inside of south wall: □ 750 mm, ○ 500 mm, △ 250 mm; measurement series: clear symbols A, dark symbols B.

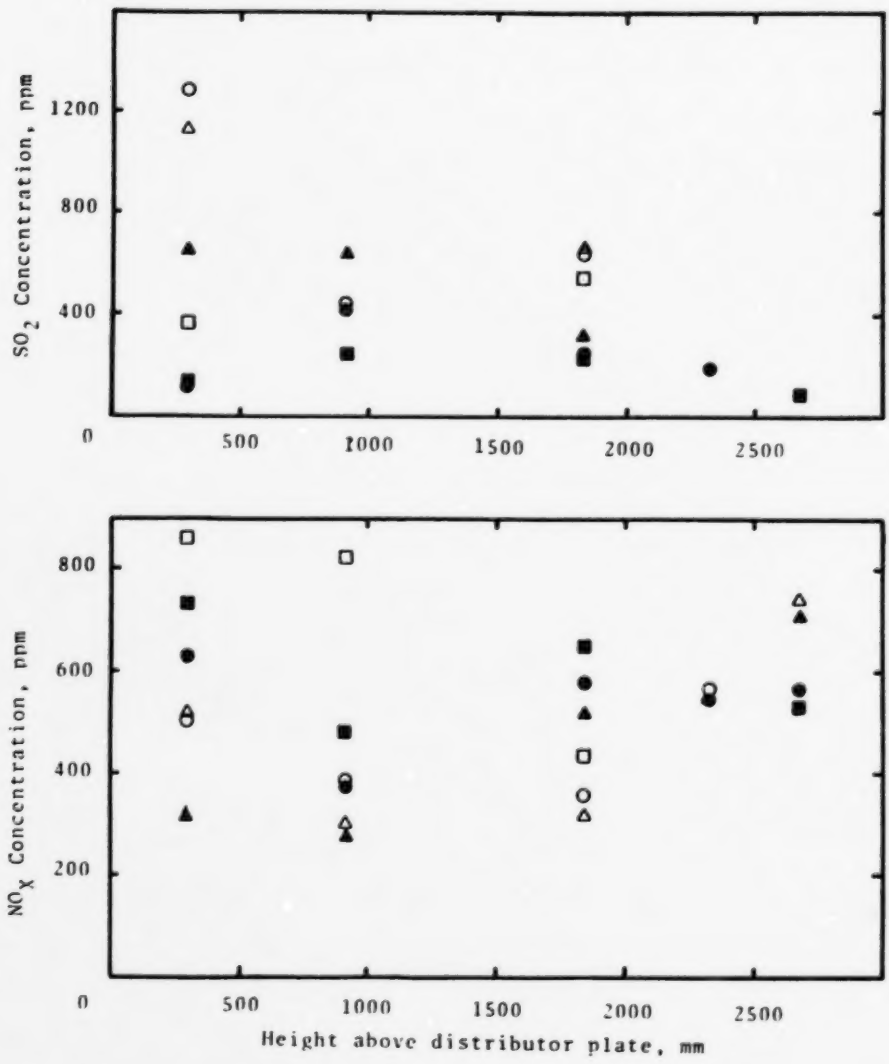


Fig. 3.7 NO_X and SO_2 concentrations in middle ports versus height above the distributor plate. Sampling locations as measured from inside of south wall: □ 750 mm, O 500 mm, Δ 250 mm; measurement series: clear symbols A, dark symbols B.

4. DISCUSSION OF RESULTS

The two sets of measurements at most ports were taken consecutively. However, those in ports S18, I16 and A16 were separated by an interval of 23 hours, 60 hours and 82 hours, respectively. Nevertheless the replicates from each of these latter ports are almost identical as can be seen in Figures 3.1 to 3.5. Hence, the average gas concentration profiles within the combustor appear to have varied little during the four day sampling period although the coal and limestone flowrates varied greatly during that period.

The average concentration of the gas species was however a strong function of both lateral and longitudinal positions within the combustor. For instance, the O_2 concentration within the bed was high in the south-east and north-west corners of the bed and low everywhere else. This might have been caused by a maldistribution of the air at the base of the bed, or more likely by the orientation of the fuel feed nozzle. The fuel feed nozzle was aimed diagonally into the north-east and south-west corners of the bed (see Figure 2.2.1) and combustion appears to have been more intense in the bed region above that diagonal as is evidenced by the O_2 traverse in ports I9 and A9 (see Figure 3.1):

-- in port I9, the O_2 concentration increased as the probe was moved away from the north-east corner, whereas
-- in port A9, the O_2 concentration decreased as the probe was moved towards the south-west corner.

Furthermore, the gases must have been moving in plug flow through the bed with little lateral gas mixing because 1) there were large lateral concentration gradients within the bed (indication of poor lateral mixing) and 2) the in-bed O_2 concentration decreased with height above the distributor plate (see Figure 3.6).

These findings are in agreement with the plume model proposed by Park, Levenspiel and Fitzgerald (1). These workers have shown that AFBCs operate in the slow bubble

regime and thus, that the gas flow pattern in AFBCs must be closely approximated by plug flow with little gas concentration difference between the bubble and emulsion phases. Hence, although the resolution of extractive gas sampling is not high enough to differentiate between the bubble and emulsion phases, this is not a severe limitation because there should be little difference in concentration between the bubble and emulsion phases at a given location within the AFBC. Furthermore, Park et al. (1) have shown that because the devolatilization of coal particles is very fast, a plume of volatiles must necessarily form above the coal feed points. This explains why lower O_2 concentrations were observed above the diagonal region along which coal was fed.

The CO and CO_2 concentrations within the bed were strongly correlated with the O_2 concentration as can be seen by comparing the results of Figures 3.3 and 3.2 with those of Figure 3.1. As expected, the CO_2 and CO concentrations were usually low where the O_2 concentration was high and vice versa. Also, the CO concentration was highest in the ports nearest to the fuel feed nozzle, confirming the presence of a highly reducing zone near the coal feed point.

As shown in Figure 3.7, the NO_x and SO_2 concentrations within the bed generally decreased with height above the distributor plate. Furthermore, it can be seen by comparing Figures 3.5 and 3.3 that the SO_2 concentration was highest in the fuel rich regions of the bed, indicating that the sulphur content of the volatiles was significant. These findings are in qualitative agreement with the model proposed by Park and Levenspiel (2) for sulphur capture in AFBCs. Also, it can be seen by comparing Figures 3.4 and 3.3 that the NO_x concentration was lowest in the fuel rich regions of the bed, in agreement with the generally accepted theory that NO_x is reduced in the fuel rich zones of the combustor (3).

The O_2 concentration profiles obtained in port W19 (see Figure 3.1) indicate that there were highly oxidizing zones

in the freeboard caused possibly by some air bypassing along the east wall. Indeed, it is evident from the O_2 and CO_2 concentration profiles along the freeboard (see Figure 3.6) that the flue gas was diluted by air near the level of port W19. Hence, it is unclear whether the decrease in SO_2 concentration along the freeboard shown in Figure 3.7 was due to sulphur capture by limestone or to the dilution effect. Furthermore, it is believed that the highly oxidizing zones found in the freeboard were the cause for the general increase in NO_x concentration along the freeboard (see Figure 3.7) and the absence of CO in that region of the combustor (see Figure 3.6).

The average O_2 readings in Port N21 are in good agreement with the O_2 concentration of 3% measured with the platinum-zirconia oxygen sensor located after the cyclone (see Table 3.1). This indicates that very little combustion occurred above Port N21.

5. CONCLUSIONS

Extractive gas sampling is an effective method for determining the gas concentration profiles within atmospheric fluidized-bed combustors. It can thus be a valuable diagnostic tool for determining the mechanisms of coal combustion and pollutant formation or capture within AFBCs.

The gas concentration measurements taken at the Point Tupper AFBC facility indicated that

-- there were highly reducing zones near the coal feed nozzle,
-- some of the combustion air was bypassing the fluidized bed, and
-- the plume model of Park et al. (1,2) appears to be a realistic representation of the gas flow patterns in AFBCs.

6. RECOMMENDATIONS

Eleven alundum filters were required to complete the gas sampling program. Some filters were broken by mistake but most were cracked by thermal shocks. Hence, if future sampling is to be done with a similar probe, it is recommended that more robust filters be used or that special precautions be taken to prevent cracking of the filters by thermal shock.

The gas concentration profiles presented herein should be compared with 1) the extractive gas sampling results obtained recently by NSPC personnel using a similar water-cooled probe but having no electrical heating along the inner gas sample line, and 2) the oxygen concentration profiles previously obtained with the platinum-zirconia oxygen sensor. This comparison will unify the results obtained by these three independent studies and will provide a sound basis for rejecting erroneous results obtained by any of the three measurement programs. The unified results will be very valuable in analyzing the results of the corrosion trials and verifying proposed mathematical models for coal combustion and sulphur capture in AFBCs.

7. REFERENCES

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2. Park, D. and Levenspiel, O.: Fuel 61, 578 (1982).
3. Hirama, T., Tomita, M., Adachi, T., Yamaguchi, H. and Horio, M.: Environ. Sci. Technol. 14, 955 (1980).

APPENDIX A
SUMMARY OF RESULTS

TABLE A.1. Summary of Results for Port E1

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	26/7	15:46					
	Average		2.04	15.67	1630	858	359
	Std. Dev.		0.43	0.41	480	38	98
500mm	26/7	16:01					
	Average		0.77	15.85	6400	450	1280
	Std. Dev.		0.22	0.22	1400	49	100
250mm	26/7	16:15					
	Average		2.58	14.10	6900	518	1110
	Std. Dev.		0.47	0.37	1400	62	250
B) 750mm	27/7	1:23					
	Average		2.51	14.94	2500	728	137
	Std. Dev.		0.51	0.20	740	34	27
500mm	27/7	1:29					
	Average		1.64	14.95	3360	627	126
	Std. Dev.		.07	0.11	640	18	20
250mm	27/7	1:35					
	Average		0.676	15.34	21800	513	655
	Std. Dev.		0.057	0.067	2800	19	51

TABLE A.2. Summary of Results for Port G3

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	26/7	12:17					
	Average		1.08	17.12	9100	592	964
	Std. Dev.		0.24	0.34	1300	55	64
500mm	26/7	12:32					
	Average		0.74	17.06	11400	555	1226
	Std. Dev.		0.25	0.42	1700	78	79
250mm	26/7	12:50					
	Average		1.23	16.61	8900	576	1190
	Std. Dev.		0.58	0.22	1200	32	100
B) 750mm	26/7	13:07					
	Average		1.29	16.46	9100	585	1280
	Std. Dev.		0.28	0.33	1300	27	110
500mm	26/7	13:23					
	Average		1.0	16.4	5200	514	1610
	Std. Dev.		0.14	0.24	1400	34	140
250mm	26/7	13:40					
	Average		1.34	15.88	6280	641	1049
	Std. Dev.		0.15	0.27	870	15	75

TABLE A.3. Summary of Results for Port A9

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	26/7	22:52					
	Average		2.37	16.28	780	627	81.5
	Std. Dev.		0.23	0.48	110	26	2.1
500mm	26/7	23:06					
	Average		1.25	16.28	1130	615.9	103.8
	Std. Dev.		0.17	0.11	150	6.3	7.5
250mm	26/7	23:20					
	Average		1.19	16.2	1690	570	129
	Std. Dev.		0.13	0.11	150	15	11
B) 750mm	26/7	23:34					
	Average		1.95	15.82	634	692	98.6
	Std. Dev.		0.20	0.22	67	22	4.5
500mm	26/7	23:47					
	Average		1.28	16.14	1030	662	120.2
	Std. Dev.		0.15	0.056	140	31	4.3
250mm	26/7	23:55					
	Average		0.93	16.01	1950	570	161
	Std. Dev.		0.12	0.08	300	17	17

TABLE A.4. Summary of Results for Port E9

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	26/7	19:57					
	Average		0.87	16.7	2910	824	242
	Std. Dev.		0.19	0.091	440	65	32
500mm	26/7	20:46					
	Average		0.50	17.44	7850	379	436
	Std. Dev.		0.18	0.42	280	20	30
250mm	26/7	21:11					
	Average		0.58	17.57	13610.	301	640
	Std. Dev.		0.13	0.26	650.	20	40
B) 750mm	26/7	21:37					
	Average		0.572	17.03	4100	478	242
	Std. Dev.		0.094	0.18	500	25	21
500mm	26/7	22:06					
	Average		0.627	17.38	7590	374	415
	Std. Dev.		0.059	0.19	320	15	30
250mm	26/7	22:27					
	Average		0.528	18.06	12930	274	635
	Std. Dev.		0.030	0.25	490	24	41

TABLE A.5. Summary of Results for Port I9

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	26/7	18:04					
	Average		2.50	14.96	790	880	120
	Std. Dev.		0.45	0.32	190	25	13
500mm	26/7	18:20					
	Average		4.14	13.53	460	817	120.7
	Std. Dev.		0.48	0.36	200	26	9.5
250mm	26/7	18:41					
	Average		6.17	11.93	53	775	108.2
	Std. Dev.		0.57	0.37	14	35	1.3
B) 750mm	26/7	18:56					
	Average		3.44	14.13	600	867	142
	Std. Dev.		0.59	0.53	270	31	21
500mm	26/7	19:11					
	Average		4.84	12.9	320	783	145
	Std. Dev.		0.41	0.29	140	28	18
250mm	26/7	19:25					
	Average		6.64	11.44	66	727	142.4
	Std. Dev.		0.57	0.51	43	29	2.5

TABLE A.6. Summary of Results for Port A16

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	23/7	14:55					
	Average		0.88	17.73	1220	511	561
	Std. Dev.		0.13	0.14	430	15	37
500mm	23/7	14:30					
	Average		3.29	15.50	46	509	432
	Std. Dev.		0.47	0.40	41	39	56
250mm	23/7	14:02					
	Average		1.16	17.63	2260	421	691
	Std. Dev.		0.65	0.13	400	16	37
B) 750mm	27/7	00:09					
	Average		0.81	17.84	1900	325	126.8
	Std. Dev.		0.082	0.91	190	56	9.5
500mm	27/7	00:16					
	Average		1.78	16.37	800	320	249
	Std. Dev.		0.10	0.088	100	13	33
250mm	27/7	00:25					
	Average		0.704	17.22	3100	306	539
	Std. Dev.		0.045	0.097	290	10	48

TABLE A.7. Summary of Results for Port I16

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	24/7	11:45					
	Average		1.91	16.96	780	409.1	436
	Std. Dev.		0.15	0.15	230	8.3	15
500mm	24/7	12:01					
	Average		3.0	15.61	240	632	361
	Std. Dev.		0.33	0.098	140	14	23
250mm	24/7	12:19					
	Average		3.22	15.45	250	659	348
	Std. Dev.		0.32	0.31	120	17	16
B) 750mm	27/7	00:37					
	Average		0.91	17.4	2350	348	241
	Std. Dev.		0.13	1.3	390	38	58
500mm	27/7	00:46					
	Average		1.19	16.53	1360	381	597
	Std. Dev.		0.014	0.07	100	17	17
250mm	27/7	00:53					
	Average		1.16	16.49	1670	390.8	696
	Std. Dev.		0.086	0.07	170	8.1	18

TABLE A.8. Summary of Results for Port S18

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	24/7	17:57					
	Average		2.11	16.93	180	435.7	471
	Std. Dev.		0.17	0.14	120	9.4	30
500mm	24/7	18:11					
	Average		1.34	17.56	240	353.8	628
	Std. Dev.		0.14	0.12	100	9.5	21
250mm	24/7	18:28					
	Average		1.46	17.46	890	317	660
	Std. Dev.		0.072	0.073	230	11	23
B) 750mm	25/7	16:37					
	Average		1.84	16.06	237	647	234
	Std. Dev.		0.094	0.13	64	30	25
500mm	25/7	16:52					
	Average		1.43	16.2	470	576	253
	Std. Dev.		0.17	0.15	130	21	18
250mm	25/7	17:09					
	Average		1.405	16.24	880	513	317
	Std. Dev.		0.095	.11	210	19	17

TABLE A.9. Summary of Results for Port W19

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	24/7	20:22					
	Average		6.02	13.59	0.	597	175.5
	Std. Dev.		0.42	0.35	0.	12	3.3
500mm	24/7	20:37					
	Average		4.81	14.46	0.	565.4	192.0
	Std. Dev.		0.29	0.26	0.	7.7	4.5
250mm	24/7	20:54					
	Average		2.31	16.8	8	564	240
	Std. Dev.		0.14	0.16	21	12	12
B) 750mm	24/7	21:19					
	Average		6.45	13.1	0.	580	166.2
	Std. Dev.		0.36	0.33	0.	14	6.5
500mm	24/7	21:38					
	Average		4.72	14.42	0.	544	190.6
	Std. Dev.		0.27	0.22	0.	14	6.8
250mm	24/7	21:56					
	Average		1.81	17.39	55	517	304
	Std. Dev.		0.18	0.27	86	16	40

TABLE A.10. Summary of Results for Port N21

Position	Date	Time	Gas Species Concentration				
			O_2 %	CO_2 %	CO ppm	NO_x ppm	SO_2 ppm
A) 750mm	25/7	12:34					
	Average		2.27	15.92	2.8	533	82.1
	Std. Dev.		0.33	0.33	8.8	15	3.0
500mm	25/7	12:52					
	Average		2.70	15.49	0.	564	82.8
	Std. Dev.		0.32	0.25	0.	21	2.1
250mm	25/7	1:09					
	Average		3.23	15.17	0.	740	85.1
	Std. Dev.		0.26	0.19	0.	23	1.5
B) 750mm	25/7	1:25					
	Average		2.76	15.37	0.	528	87.8
	Std. Dev.		0.29	0.24	0.	10	2.4
500mm	25/7	1:41					
	Average		2.98	15.15	0.	567	87.3
	Std. Dev.		0.24	0.21	0.	15	1.6
250mm	25/7	1:57					
	Average		3.48	14.88	0.	708	89.7
	Std. Dev.		0.28	0.29	0.	26	1.9